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Correlation Between the System Capabilities Analytic Process (SCAP) and the Missions and Means Framework (MMF)

by Kevin S. Agan

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14. ABSTRACT
This report is the culmination of over 3 years of discussions, meetings, and forums on how the System Capabilities Analytic Process (SCAP) and Missions and Means Framework (MMF) correlate and where they diverge. An overview of each paradigm, as well as a discussion of why they should be correlated, will be presented. The specifics of the correlation will be explored followed by discussion of new paradigms— the ordered event list (OEL) and the decision tree— that result from this aggregation. This report will conclude with a discussion about the benefits of correlating SCAP and MMF. The intent of this report is not to inseparably link the two paradigms into a single entity, but to compare two semi-parallel, complementary paradigms.

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This report is the culmination of over 3 years of discussions, meetings, and forums on how the System Capabilities Analytic Process (SCAP) and Missions and Means Framework (MMF) correlate and where they diverge. As such, this report would not have been possible if it were not for the discussion, feedback, and support from the following individuals. In no particular order, I would like to extend personal thanks to Lt. Col. (Ret) Brit Bray (Dynamics Research Corporation), Lee Butler, Dr. Paul H. Deitz (Army Materiel Systems Analysis Activity), William Landis, Lt. Col. Richard Moyers, James Nealon, Jack Sheehan (ORSA Corporation), Dr. Paul Tanenbaum, and Beth Ward.

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1. Introduction

Most military systems are usually complex vehicles or hardware that provide very specific capabilities to the warfighter. This is especially true for more modern vehicles that are starting to rely on extensive communications and computer networks to share information between the Soldiers, their vehicles, and other organizations and personnel. Therefore, the concept of a standalone system, which is typically how most systems have historically been defined, analyzed and tested, is quickly becoming obsolete. Additionally, the typical standalone analysis could likely have output metrics that may not be easily understood by the military end user.

To alleviate this issue, analyses need to be conducted in a way that maintains the context of how a system is used (e.g., where, when, why, how, and by whom) and produces metrics that are easily understood by the military end user. Two such analysis paradigms, the System Capabilities Analytic Process (SCAP) and the Missions and Means Framework (MMF), fit these criteria. SCAP is an analysis paradigm that allows for a quantitative understanding of what capabilities are provided by a system, whereas MMF is a paradigm that allows for an understanding of missions and how systems are utilized within these missions.

Additionally, decisions in combat about what actions are to be taken to accomplish an objective are partially based on what people and equipment are available and what capabilities they provide. As such, an analysis methodology is needed, in which the outputs of the mission analysis are in terms that can correlate to the capabilities-based decisions that are employed by the battle commander.

1.1 What Is SCAP?

SCAP is a methodology that was developed for use by the U.S. Army Research Laboratory (ARL) for the criticality analysis of ground combat vehicles (Agan, 2010a) and for the correlation of vehicle assessments from live-fire tests to vehicle performance (Landis, 2010a; Agan and Landis, 2010a). The primary product from applying SCAP to a ground combat vehicle is the construction of a map between the system's components and its measurable capabilities known as the Functional Skeleton (FS) (Agan, 2010a), which is analogous to the systems engineering process of functional analysis (Kossiakoff and Sweet, 2003) and generates a system architecture (Agan, 2011a; Agan, 2012a).

1.2 What Is MMF?

MMF is a paradigm that is used to explicitly specify a military mission and quantitatively evaluate the mission utility of alternate organizations and/or systems (Sheehan et al., 2004a). The entire MMF process deals with entities that are discrete and observable (Deitz et al., 2009). In the words of Sheehan et al. (2004a), MMF is "a disciplined procedure to explicitly specify the mission, allocate means, and assess mission accomplishment." In the words of Deitz et al. (2009), "MMF simply provides an explicit and logical structure for executing what military operators call the military decision-making process (MDMP)."*

1.3 Why Correlate SCAP and MMF?

There are multiple reasons why SCAP and MMF should have a conclusive correlation.† The first reason is that SCAP can supplement the MMF by providing a quantitative understanding of the system performance after an event changes the component state or functional performance of the system. This understanding could allow for a better assessment of task and mission accomplishments within the MMF. Conversely, the MMF can advise an analyst on how a system is to be utilized in a mission context, which will allow for a more comprehensive construction of the FS.

Additionally, there is a risk of the persistent misunderstanding of how the two paradigms correlate and complement each other. Since the initial evolution of SCAP in 2009, personnel (both internally and externally) from ARL have inquired about how the two paradigms complement or detract from each other (Agan, 2009a, 2009b, 2010b, 2010c, 2010d; Landis 2010b, 2010c; Agan and Landis, 2010b, 2010c; Agan and Mitchell, 2012). Specifically, there have been concerns that SCAP is a replication of the MMF (Agan and Mitchell, 2012), or that it is a potential supplanting paradigm (Bray, 2012; Agan and Mitchell, 2012; Agan, 2012b). Neither of these concerns is true as will be explained in this report.

Finally, there have already been attempts at correlating SCAP and MMF (Agan, 2009a, 2009b, 2010b, 2010c, 2010d, 2010e, 2012b, 2012c; Bray, 2012; Grazaitis and Ruth, 2012; Nealon, 2011, 2012a), but none of the previous efforts explicitly or conclusively correlated the elements of SCAP and MMF into a complementary paradigm. All of these previous attempts implicitly correlated the paradigms and assumed both a considerable understanding of the two paradigms by the audience and their ability to see the linkage for themselves (Agan and Nealon, 2012).

Because of these issues, a risk exists that the two paradigms could be improperly correlated, which could result in significant errors in an analysis and/or make the analysis too difficult to complete.

---

* The MDMP is the Army's formal methodology for tactical decision making (Burwell, 2001), primarily for conventional warfare (Hales, 2005). It is a planning methodology that is used to understand the situation in the active mission, develop the available courses of action, determine which course of action is best for accomplishing the mission, and produce the relevant operation plans or orders of execution (ATTP 5-0.1, 2011). The MDMP is an institutionalized form of U.S. Army experience formally adopted in 1960, but is based on the Army's "Estimate of the Situation Process," which has been doctrine since 1910 (Marr, 2001). There has been a number of revisions to the foundation documents for the MDMP - most notably the FM 101-5 series through the year 2005 (FM 101-5, 1932) (FM 101-5, 1950) (FM 101-5, 1960) (FM 101-5, 1968) (FM 101-5, 1972) (FM 101-5, 1982) (FM 101-5, 1984) (FM 101-5, 1997) and subsequently the FM 5-0 series from 2005 to present (FM 5-0, 2005) (FM 5-0, 2010) (ADP 5-0, 2012). The current, comprehensive treatment of the MDMP can be found at ADP 5-0 (2012) and chapter 4 of ATTTP 5-0.1 (2011).

† It is important to note that the intent of this report is not to inseparably link the two paradigms into a single entity but to compare two semiparallel, complementary paradigms.

1.4 Outline of the Discussion in This Report

This report will serve as the formal correlation between SCAP and MMF, and it will discuss where the two paradigms are able to complement each other and also discuss where they diverge. To accomplish this objective, the discussion will begin with a concise overview of both paradigms in sections 2 and 3 that focuses on the concepts that are critical for a correlation to occur.* The correlations between the two paradigms will then be presented in section 4, which will also include the introduction of additional concepts that are possible due to this correlation. Section 5 will contain a brief discussion about some of the benefits that result from this correlation that have not already been discussed in the beginning of section 1.3.

2. Overview of SCAP

2.1 General Description of a Criticality Analysis

A criticality analysis is the process of examining a system to determine which components of that system are required for the system to perform as intended and the severity of the consequences if these components are dysfunctional (Dhillon 2007). A component is considered critical when damage to, or the failure of, the component can affect the performance of one or more of the system's primary mission functions. The results of component dependency in a criticality analysis are presented in diagrams known as fault trees (Agan, 2010a; Vesley et al., 1981).

2.2 An Overview of the General Structure of SCAP

SCAP in itself is not the product, but instead it is a thought process that is to be used during an analysis of a system to build an understanding of how the system performs, as well as what physical elements of the system provide that functionality. Therefore, the levels as shown in figure 1 are not only the various elements of the FS, but they are also a way of viewing the system and how it is decomposed between mission task and physical components. All data in these levels are explicit, quantitative, and in the terms of the military user and/or system designer. What follows is an overview of the FS with more detail about these elements found in Agan (2010a).

The lowest two levels of the FS are the component and subsystem, which make up the physical elements of the system, hereafter known as the "physical construct" (Agan, 2012a). The components are the piece parts of the system under study and are the lowest level of the analysis. The component can be individual parts like shafts, bolts, or wires, or it can be a functional subassembly that will not be disassembled during service, such as an electric motor. A

* A comprehensive review of SCAP can be found in Agan (2010a), and a detailed discussion of MMF can be found at in Sheehan et al. (2004a) and Deitz et al. (2009).

subsystem is a collection of components that are assembled together for a specific purpose. For example, a subsystem on a commercial light-duty truck (LDT) can be a fuel system, which is built from various hoses, tanks, pumps, and other special components.

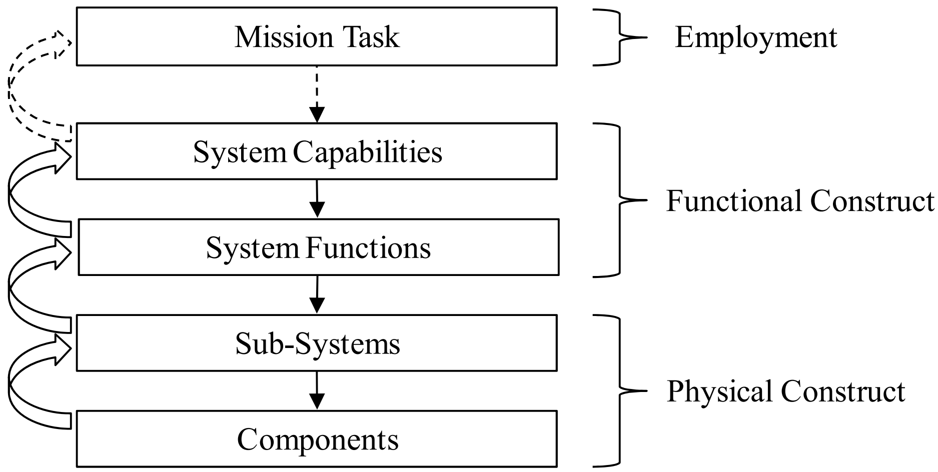

Figure 1. Overview of the levels within the SCAP FS.

The next two levels on the FS are the measurable performances of the system, known as the system functions and the system capabilities, hereafter known as the "functional construct" (Agan, 2012a). The system functions are typically the measurable actions or performances of one or several subsystems. For the LDT mentioned above, the fuel system can provide the system functions "store fuel" and "provide fuel to the engine." The system capabilities are measurable performances of the whole system that are produced from when one or many system functions are aggregated for a specific purpose. For example, the LDT would have a system capability of "travel on roads," which is possibly due to the aggregation of multiple system functions, such as "generate power from fuel," "transfer power to the wheels," and "maintain traction." These system functions are allocated to the engine system, axles, and wheel systems, respectively. The system capability can also be decomposed into bins, which represent the various magnitudes of performance (Agan, 2010a). For the system capability of travel on roads, a LDT can be notionally represented by bins consisting of max speed of 75 mph, 50 mph, 25 mph, 5 mph, and 0 mph (Agan, 2010a; Deitz et al., 2009).

Unlike typical system architectures, which consider the human operator outside the system boundary (Kossiakoff and Sweet, 2003), the FS includes the human operator as an integral element. The human is applied as a critical subsystem, and the actions and functions the human provides are allocated to the appropriate system functions. For the LDT, assume that there is a system function "maintain directional control." The two subsystems that would be allocated to this function are the steering system and the human driver.

It is very important to note that, unlike traditional criticality analyses (Ploskonka et al., 1988; Van Dusen et al., 1989; Dougherty, 2005), which document consequences when physical or functional elements are lost (i.e., "killed"), SCAP and the FS document what can be maintained by considering what is available. Therefore, the presence and proper operation of critical elements in the system can aggregate up through the FS and tell the analyst what can be accomplished. However, the FS can still be used to identify what capabilities are no longer available, if specific elements are deemed dysfunctional. This dichotomy allows the FS of a single system to assess both what it can and cannot accomplish.

The mission task, also known as system employment, is not a part of the FS but is instead included in the execution of the analysis to guide the analyst on what system capabilities are critical and required. For the LDT, the ability to travel on roads at a specified speed is nice to know, but it is only critical if the mission under analysis requires that capability. If the mission is to idle in a specified location with the climate system providing comfort to personnel, then the ability to travel on roads is not critical for that mission.

Based on the preceding discussion, a sample of the FS for a LDT is depicted in figure 2. In this example, the military user wants to use this LDT to conduct a raid on a target area, which requires multiple system capabilities.

2.3 Relationships Between the Levels Within the FS

In typical criticality analyses (Ploskonka et al., 1988; Van Dusen et al., 1989; Dougherty, 2005), the relationships between the various levels are accomplished via a construct known as the fault tree, which aggregates undesirable events into larger undesirable states and conditions (Dhillon, 1998; Vesely et al., 1981). Conversely, because a SCAP analysis will determine what is possible based on desirable states, the relationships between the levels will be known as an activation tree. However, the mechanics and mathematics used by a fault tree and activation tree are identical.

The fault tree/activation tree mechanics are simple. If a path can be tracked from the start of the tree through to the end, then the tree is considered functional (Ploskonka et al., 1988). The tree can be made up of either series or parallel relationships as shown in figure 3. A series relationship is shown between "element 1" and "element 2," and a dysfunction for either element will cause the entire tree to become dysfunctional (Vesley et al., 1981). A parallel relationship is shown beneath "element 2," which branches to "element 3" and "element 5." To make a parallel relationship dysfunctional, all branches must be dysfunctional (Vesley et al., 1981).

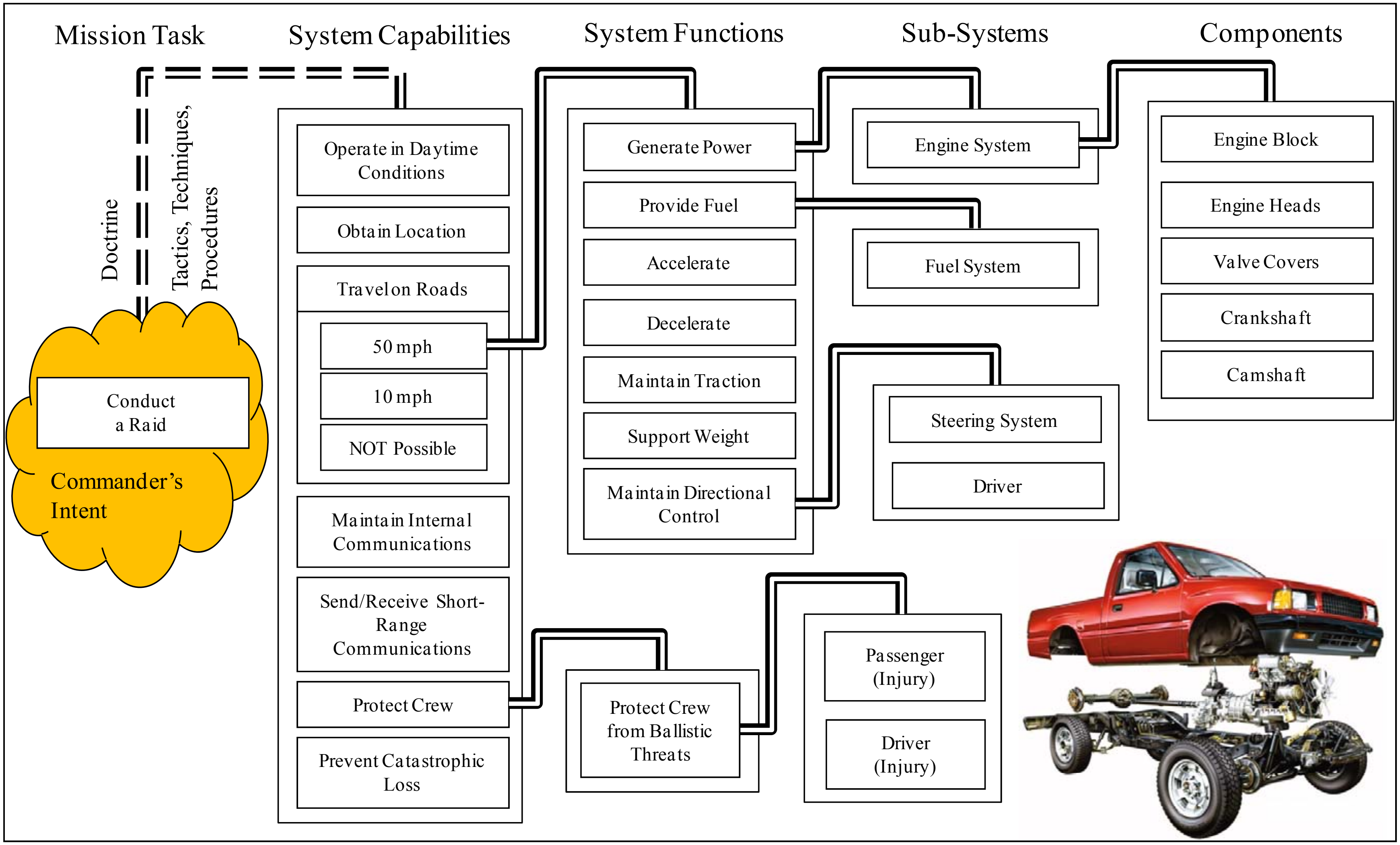

Figure 2. A sample FS for a LDT.

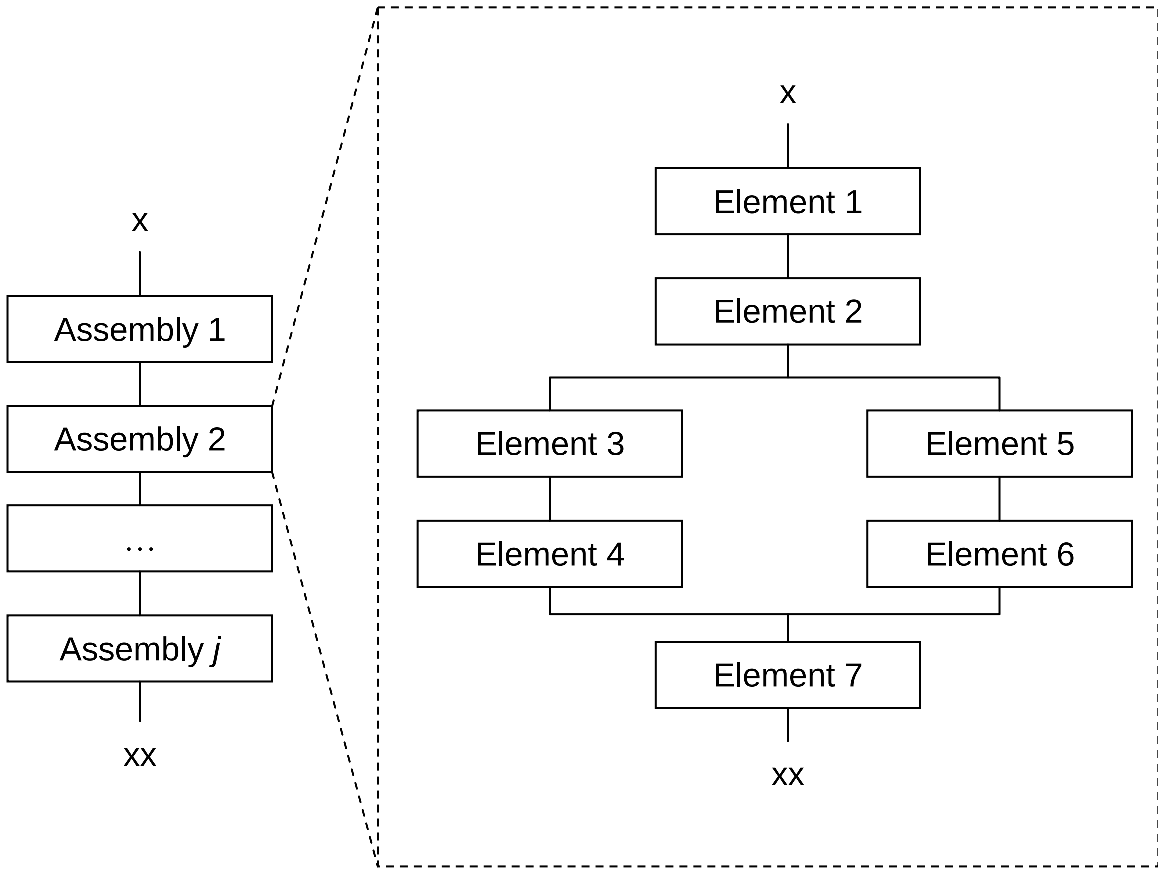

Figure 3. A depiction of a notional fault/activation tree.

For the activation tree, each element can be represented as either functional and assigned a value of 1, or dysfunctional and assigned a value of 0. Series relationships are represented by the product sum of the elements, shown in equation 1, and parallel relationships are computed using the survivor sum, shown in equation 2 (AJEM, 2011; Dhillon, 1998; Deitz and Starks, 1998; Tobias and Trindade, 1986). By applying both of these concepts to the activation tree, shown in figure 3, the analyst can develop the formula for the availability of the whole tree, as shown in equation 3 (Bazvosky 1961; Aven 1992):

$$A_j = \prod_i^n (E_i). \tag{1}$$

$$A_j = 1 - \prod_i^n (1 - E_i). \tag{2}$$

$$A_2 = E_1 \cdot E_2 \cdot \left\{1 - \left\{\left(1 - \left(E_3 \cdot E_4\right)\right) \cdot \left(1 - \left(E_5 \cdot E_6\right)\right)\right\}\right\} \cdot E_7. \tag{3}$$

3. Overview of MMF

MMF comprises 11 fundamental elements, which are depicted in figure 4 (Sheehan et al., 2004). Seven of these elements are known as "levels," which contain information about the mission specifications and the systems that are required to complete these missions: L1, L2, L3, L4, L5, L6, and L7 (Sheehan et al., 2004a). Four of the elements are known as "operators" and are used to transform the states of one of the levels to a useable form in a higher echelon level: $O_{1,2}$, $O_{2,3}$, $O_{3,4}$, and $O_{4,1}$ (Sheehan et al., 2004a). These elements are separated into two classes: the Missions and the Means (Sheehan et al., 2004a).

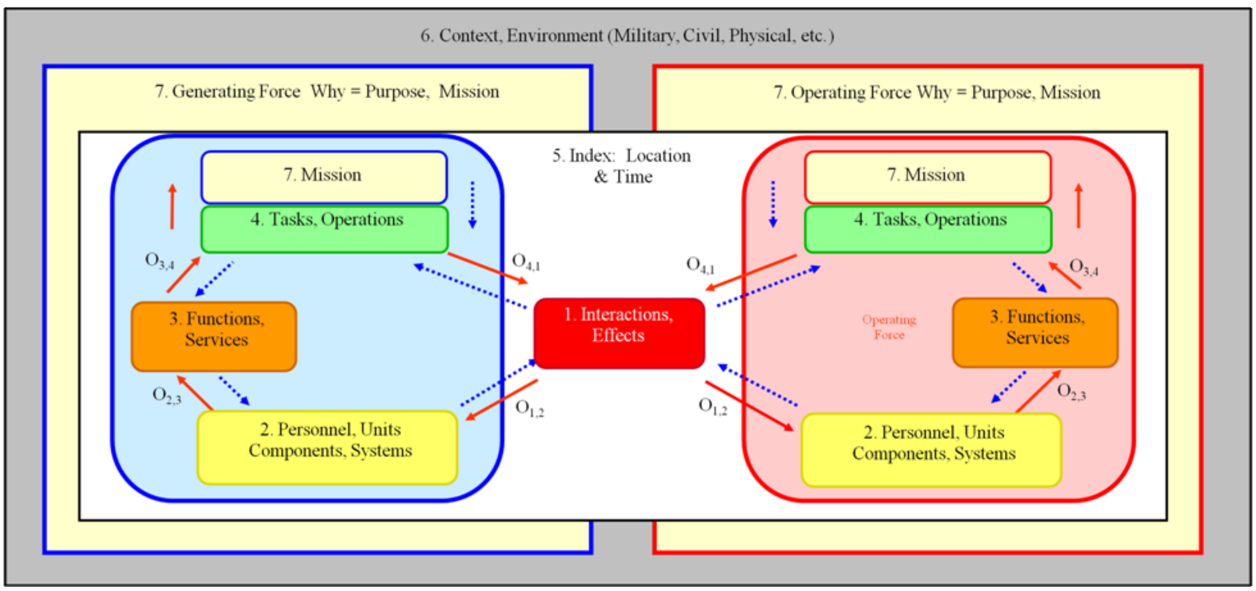

Figure 4. MMF.

An inspection of figure 4 reveals a two-sided nature of MMF (Sheehan et al., 2004a). On the left is "generating force," hereafter referred to as the "own force" (OWNFOR). The OWNFOR are considered the friendly forces in a mission (Deitz et al., 2009). The right side represents the "operating force" or "opposing force" (OPFOR). The OPFOR represents the unfriendly forces in a mission (Deitz et al., 2009). Because of the two-sided nature of MMF, the actions of the OWNFOR will influence the outcome of OPFOR's mission, and vice versa (Sheehan et al., 2004a).

3.1 Missions

The "Missions" are the specifications associated with the L7, L6, and L5 (Sheehan et al., 2004a). Collectively, these define the actions and the environment in which a mission is accomplished. The process used to decompose missions into tasks will not be addressed within this report, as a full treatment of mission decomposition is not necessary to affirm the correlations discussed in section 4. However, the process is thoroughly addressed in other documents, which are accessible to the interested reader.*

3.1.1 Level 7: Purpose/Mission

The Level 7 Purpose and Mission focuses on the details of how a system or organization are being employed, that is, it defines "why" and the "wherefore" of a military evolution (Sheehan et al., 2004a). This can also be viewed as the purpose of actions that must be done to achieve a specified outcome (Nelson and Bealy, 2006).

3.1.2 Level 6: Context/Environment

The Level 6 Context and Environment defines the circumstances for how a L7 Mission is to be accomplished (Sheehan et al., 2004a). These circumstances can include the military, civil, and physical context, and the environmental conditions that determine the actions that are required to accomplish the mission (Nelson and Bealy, 2006).

3.1.3 Level 5: Index, Location/Time

Level 5 contains the temporal and geospatial specifications of the mission under analysis. As such, L5 will detail the "where" and "when" of the mission (Sheehan et al., 2004a) and actions across the full evolution (Nelson and Bealy, 2006).

3.2 Means

The "Means" are the specifications associated with levels 1 through 4, as well as the operators between these levels (Sheehan et al., 2004a). Collectively, these elements define the "what" of the mission accomplishment and specifically identify the resources required and their relevant actions.

3.2.1 Level 4: Tasks/Operations

The Level 4 Tasks/Operations are the specifications of how a system or organizations within the Means execute specific actions within the mission. In the words of Sheehan et al. (2004a), they are "the 'do what' named-with-a-verb 'playbook' of military evolutions." These actions are compiled via a thorough analysis of L7 and an understanding of L6 and L5 (Sheehan et al., 2004a). The purpose of L4 is to construct a series of task outcomes, along with the appropriate measures, that are needed to evaluate success/failure of the overall mission (Sheehan et al., 2004a).

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* Per Agan and Bray (2012) there are a number of sources that detail how to conduct a mission analysis, the process that is used to identify the tasks that are required to achieve the mission. Most of these publications are Army training publications that discuss the techniques and employed practices. A concise description of mission analysis can be found in ATTP 5-0.1 (2011) in pages 4-6–4-14 with a focus on identification of the tasks found in 4-7–4-8. Comprehensive treatments of how to decompose a mission into tasks can be found in FM 7-1 (2003) and JMETL (2002) with additional treatments at TRADOC Pamphlet 350-70-1 (2012), ADRP 7-0 (2012), and CJCSI 3500.01C (2006).

3.2.2 Level 3: Functions, Capabilities

Level 3 is a set of specifications that describe the measurable performances of the system or organization. In the words of Sheehan et al. (2004a), they are "the function-based, performance-centric 'how well' specification of the Capabilities that enable Forces to conduct Operations." (Sheehan et al., 2004a)

3.2.3 Level 2: Components, Forces

Level 2 is the actual systems or organizations that are to be used to accomplish the mission. These are considered the "nouns" of the specification, and can seen as the "by-whom" specifications (Sheehan et al., 2004a). These specifications can be organizations across the military hierarchy, as well as the physical design of the systems being used. This level can also include the human warfighter (Sheehan et al., 2004a) as an individual or organization.

3.2.4 Level 1: Interactions, Effects

Level 1 is where the interactions between OPFOR and OWNFOR occur. Level 1 also describes the effects and consequences of these interactions. These interactions and effects are based in the relevant phenomena, such as physics, chemistry, sociology, etc. (Sheehan et al., 2004a).

3.3 Operators Between the Levels

Between each of the four levels in the Means is a family of elements called the Operators. These Operators are what transform information from one level to the next. The Operators are denoted with the form $O_{i,j}$, where *i* is defined as the source level, and *j* is defined as the target level of the Operator.

Each Operator has an employment aspect, represented by the dashed red arrow in figure 4, and a "synthesis" aspect, represented by the blue arrow in figure 4 (Sheehan et al., 2004a). Employment is defined as the actual execution of the mission and can be seen as the actual outcomes that occur as a mission progresses (Sheehan et al., 2004a; Nelson and Bealy, 2006). Synthesis is the backward planning and decision-making process that is utilized to define and design the mission and adjust its outcomes (Sheehan, et al., 2004a). It is very important to note that employment and synthesis are not mathematical inverses (Sheehan et al., 2004a) but instead can be seen as what actually happened versus what was desired.

3.3.1 $O_{1,2}$ Operator

The $O_{1,2}$ operator is an assessment of the change of state of L2 components or Forces as a result of an applied L1 interaction or effect. In the words of (Sheehan et al., 2004a), "$O_{1,2}$ transforms Level-1 interaction specifications into Level-2 component states." Conversely, $O_{2,1}$ is the synthesis operator that represents the time-backward planning, which is used to select what interactions will be needed to impose a desired state onto L2 (Sheehan et al., 2004a).

3.3.2 $O_{2,3}$ Operator

The $O_{2,3}$ operator is used to determine how the functional state of a L3 performance changes as a result of a change in the state of L2 (Sheehan et al., 2004a). Conversely, $O_{3,2}$ is the synthesis operator that represents the time-backward planning used to select the appropriate L2 to achieve a desired L3 (Sheehan et al., 2004a).

3.3.3 $O_{3,4}$ Operator

The $O_{3,4}$ operator assesses how the L3 performance affects the L4 effectiveness (Sheehan et al., 2004a). It is through this operator that if a L3 performance is known, its contribution or impact on L4 can be determined. Conversely, $O_{4,3}$ is the time-backward planning, which is used to identify the L3 performance required to complete an L4 task (Sheehan et al., 2004a).

3.3.4 $O_{4,1}$ Operator

The $O_{4,1}$ operator is where the actions of one side of the MMF paradigm are used to define the appropriate L1 interactions that will affect the L2 state of the other side of the MMF paradigm. It is through this operation in which the phenomena mentioned in section 3.2.4 are identified. Conversely, the $O_{1,4}$ synthesis operator is the time-backward planning that is used to identify what actions are required to produce the desired L1 interactions and effects, which will ultimately produce the desired L2 component state of the opposite side of the MMF paradigm (Sheehan et al., 2004a).

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4. Correlation Between SCAP and MMF

The correlation between SCAP and MMF is straightforward: the SCAP FS can be used to compose the quantitative portion of the Means architecture (Agan and Deitz, 2012; Deitz and Walbert, 2012) by supplying a system-level architecture that represents how the current state of the physical system produces the desired performances (Agan, 2011a). As can be seen in figure 5, the quantitative portion of the Means is represented by L1, L2, L3, and the operators between them, which means they can be explicitly mapped and defined in an analysis (Agan and Deitz, 2012).[*, †] The qualitative portion of the Means are the L4, $O_{3,4}$, and $O_{4,1}$, which means that only a portion of the whole can be explicitly mapped as these relationships are highly subjective based on the evolving scenario and the decisions of the Commander within the

[*] Graphic adapted from Deitz and Walbert (2012). However, the briefing as shown at the NDIA conference (Deitz and Walbert, 2012) showed the line separating the subjective and objective elements of MMF passing through $O_{3,4}$ and $O_{1,2}$, which placed L1 as subjective. Subsequently, this chart was updated to show the demarcation occurring through $O_{3,4}$ and $O_{4,1}$, which placed L1 as objective and quantifiable (Agan and Deitz 2012a, 2012b).

[†] The quantitative portion of the graphic has been historically objective and quantified (Agan and Deitz 2012a, 2012b.)

mission (Agan and Deitz, 2012).* It is because of this separation between the qualitative and quantitative portions of MMF that SCAP can be used as a complementary paradigm and not as a competing one (Agan and Deitz, 2012).

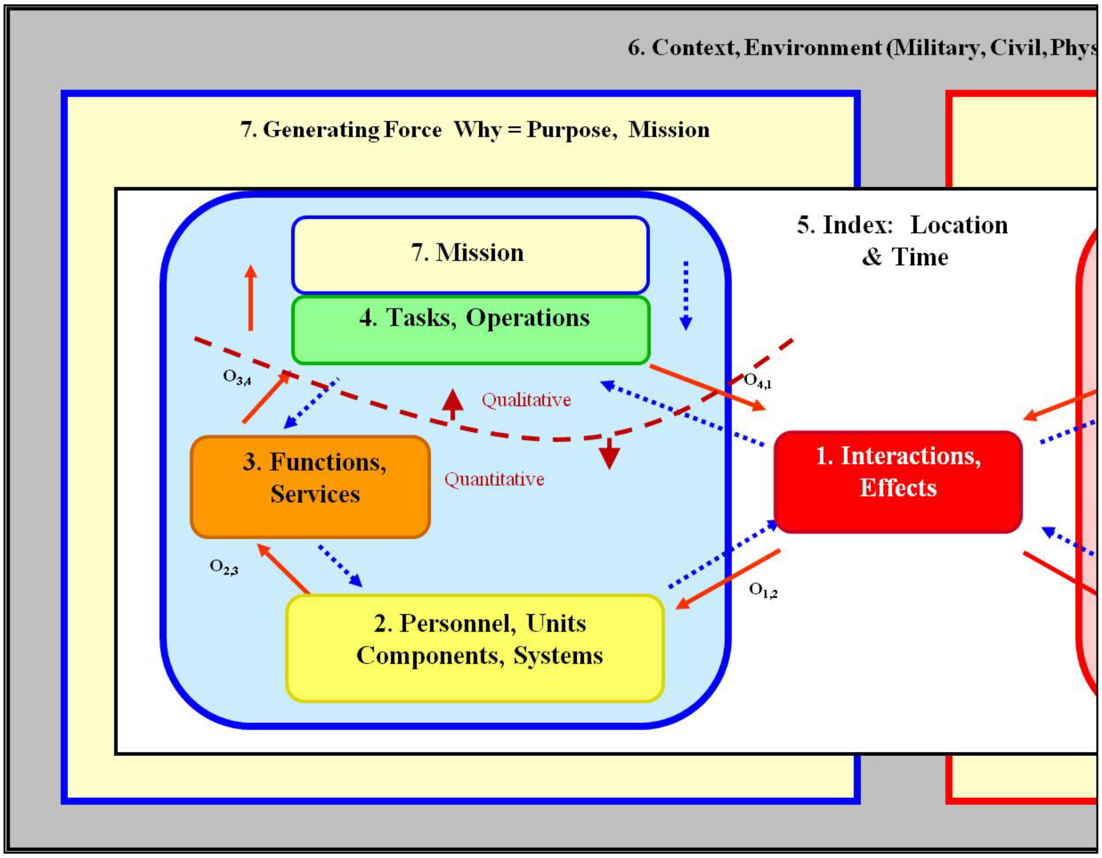

Figure 5. Depiction of the quantitative versus qualitative portions of the Means.

This correlation is further strengthened due to comments within (Sheehan et al., 2004a) that speak to the flexibility of the design of MMF. Primarily, MMF was designed to be compatible with the Department of Defense Architecture Framework (DoDAF) (Sheehan et al., 2004a; DoDAF volume I, 2007; DoDAF volume II, 2007; DoDAF volume III, 2007; Watkins, 2003, 2005), which is associated with the systems engineering concepts of functional analysis and systems architecture (Deitz et al., 2009; Kossiakoff and Sweet, 2003). Because SCAP is an applied form of functional analysis, with the FS being a form of a system architecture (Agan, 2011a, 2012a), then it can be used to build the system architecture that is required for the quantitative portion of the Means.

Further examination of (Sheehan et al., 2004a) reveals the following postulates:

* The qualitative portion of the graphic has been historically subjective and not well quantified (Agan and Deitz, 2012a, 2012b.)

1. One of the key objectives [for MMF] is to: "account for the tangible, physical, objectively measurable factors (traditional testing and evaluation)…"
2. Another key objectives [for MMF] is to account for "… the intangible, cognitive, ultimately subjective factors (traditional warfighter expertise) that constitutes mission success."

Both of these postulates again point to a correlation between MMF and SCAP, as these postulates exist in some analogous forms in SCAP's fundamental documentation. Postulate 1 is speaking to the quantitative portion of the MMF discussed above, of which the FS has already been deduced as a viable paradigm. Unlike MMF, SCAP does not create mission architectures (Agan, 2010a) as described in postulate 2, but it can inform these mission architectures by providing a link between the system capabilities and the mission task as shown in figure 2.

4.1 Piece-By-Piece Correlation Between SCAP and MMF Elements*

Based on the premises already discussed, the functional skeleton is the system-level architecture that is mapped into the various elements of the MMF paradigm. These correlations are defined in table 1. Additionally, several elements and processes within SCAP correlate to MMF elements that are outside of the Functional Skeleton, described in table 2.

Table 1. Correlations between the elements within the SCAP FS and the elements of MMF.

SCAP Elements in the FS	MMF Element
Physical construct: components and subsystems	L2
Activation trees that describe how the physical construct relates to the functional construct	$O_{2,3}$
Functional construct: System Functions and System Capabilities	L3
FS	L2, L3, $O_{2,3}$

Table 2. SCAP-related elements outside of the FS that correlate to MMF.

Elements Informed/Employed by SCAP	MMF Element
Phenomena that interact with the physical construct, which could potentially change the state of one/many components	L1
Assessment/Analysis/Physical damage that causes a component to become unavailable due to an interaction	$O_{1,2}$
Activation trees that describe how a system is employed by mapping its system capabilities to a mission task	$O_{3,4}$
An action or series of actions that define the desired goal of employing the system capabilities, known as the Mission Task.	L4

These correlations exist due to the synonymous nature of the elements between the two paradigms. The physical construct, which represents the physical elements of the system, correlates directly with the definition of the MMF level 2. The functional construct, which represents the measurable performances of the system, correlates directly with the MMF level 3.

* This correlation has been discussed at many forums, particularly those as stated in section 1.3, but this paper is the first formal, explicit documentation of the correlation between the paradigms. This correlation was affirmed prior to the composition of this paper in Agan (2011b) and Agan and Deitz (2012).

The activation trees between the subsystems and the system functions, which define what performances the constituent piece parts can produce, directly correlates with the MMF $O_{2,3}$. Therefore, the FS in its entirety will map to L2, L3, and $O_{2,3}$.

The correlations between MMF L1 and $O_{1,2}$ are not directly associated in the FS, but they can still be addressed via SCAP. The functional skeleton will assess what functions and capabilities a system can provide if the availability of the physical construct are known, either in an available (functional) or unavailable (dysfunctional) state (Agan, 2010a). Because the FS doesn't delineate why a component may be dysfunctional, it can assess the remaining performance for the whole system if any form of interaction causes a change in state (Agan, 2010a, 2011a). For example, the source of the dysfunction may be damage caused by combat, reliability failure, user abuse, environmental factors, or any number of other sources. These interactions directly correlate with the MMF level 1, and their effects on the component states are the MMF $O_{1,2}$ (Agan and Deitz, 2012a).

Similarly, the quantitative maps between the system capabilities and the mission task (system utilization) are not a part of the FS but are instead informed by the understanding of how the system will be used in specified missions (Agan, 2010a). If the missions of interest are fully defined, then it is possible to build activation trees between the mission tasks (FM 7-15, 2009; CJCSM 3500.04F, 2011) and the system capabilities for only those missions using the $O_{4,3}$ operator. These maps between system capability and mission task directly correlate to the $O_{3,4}$, as they provide the measures of performance (MoP) required to complete the mission (Sheehan et al., 2004a; Agan, 2012a; Agan and Deitz, 2012a). The mission tasks under study will correlate to L4 (Sheehan et al., 2004a; Agan and Deitz, 2012a), and the mission of interest is the fully defined L7 (Agan and Deitz, 2012a). If, for some reason, the assumptions or conditions that were used to define the $O_{3,4}$, L4, or L7 were to change, then it should be possible to modify the activation trees within $O_{3,4}$ without reconstructing the FS (Agan and Deitz, 2012a).

4.2 Ordered Event List

By employing the FS in conjunction with the equivalent MMF elements, it is possible to build a detailed ordered event list (OEL) that can define how the interacting systems in OPFOR and OWNFOR influence and ultimately change the states and performance of each other. The OEL was initially introduced by (Nealon, 2011, 2012a) to describe how missions could change based on employment of obscurant countermeasures in combat. The OEL is also an adapted tabular form of a construct known as a "decision tree" from the field of decision analysis.*

The OEL is not intended to be inclusive of all actions, outcomes and interactions of all possible missions, but is intended to capture a well-defined decomposition of some of the relevant and likely events within a specific mission (or set of missions) of interest. As long as the analysis

* A comprehensive treatment of "decision trees" and "decision analysis" can be found in Raiffa and Schlaifer (1961) and Edwards et al. (2007).

remains within this expected scope, then the OEL will provide a means to understand how the interactions between systems will influence each other. However, if the scenario under study were to change in some way, or if the assumptions used to build the OEL were to change, then the OEL would have to be updated to reflect this new intent and/or information.

4.2.1 Brief Overview of the Decision Tree Paradigm

Simply defined, a "decision tree" is a graphical depiction of what decisions are made within a known scenario, when they occur, and the identification of the consequences. A generic tree is shown in figure 6. A decision tree works on the principle that every action and decision will have a likely set of possible outcomes, which are then drawn as children to that decision/action. Each of these outcomes will then have a set of decisions that will have to be made, which are also depicted as children in the diagram. These subsequent decisions will also have a set of outcomes, which are then depicted. This process will repeat until the desired level of fidelity that is required by the analysis is achieved.

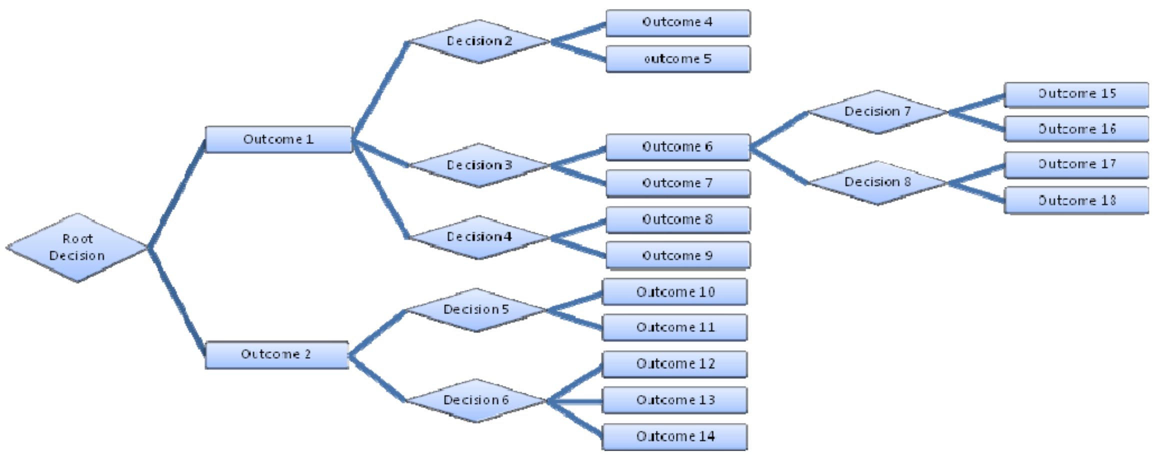

Figure 6. A generic decision tree.

4.2.2 OEL Explained

The key purpose of the OEL is to track the plethora of information that is generated when a mission evolves over time (an incrementing L5 index), as well as the various conditions on the systems (L1 and L2) within the mission that cause changes in their performances (L3). This change in the performance could likely change the performance of the mission tasking (L4) or initiate actions that were not anticipated at the beginning of the mission (L7). This performance change can also include a set of contingent or dependent actions and interactions (L4 and L1) that occur following a particular event (L1), which, in turn, generates changes to system components and functions (L2 and L3). To keep track of this information, the OEL is a table that contains at least the following information:

1. The incremental L5 indices.
2. The actions (L3 and L4) that are occurring within OPFOR and OWNFOR for each L5.

3. The L1 interactions that are occurring between OPFOR and OWNFOR.
4. The changes in states for the L2, L3, and L4 as a result of the $O_{1,2}$.
5. The critical data, parameters, and assumptions that is relevant to any of the Means' elements for the specific L5.
6. Optionally, it can include a description of any of the analytic tools or techniques that can be used to assess the $O_{1,2}$, $O_{2,3}$, or $O_{3,4}$ at the specific L5.

There is currently no formal format for how the OEL is constructed. The OEL can be very detailed or be written in generalities, based solely on the needs of the analysis or the fidelity of the information available. The incrementing L5 indices follow a specific set of guidelines that occur over the course of all interactions within an L7 Mission:

1. An OEL exists for all possible combinations of system pairings within the specified L7 Mission. Only when interactions occur or at specific time-steps will information be entered into the appropriate OEL cell. If no interactions occur between two systems of interest during the specified L7, then the OEL will only contain the three lines of I(0) initial conditions, I(N) final conditions, and I(N+1) mission evaluation.

2. I(0) is defined as the initial index where OPFOR and OWNFOR are able to interact for the first time (Nealon, 2012a). No interaction is set to occur at this point but is instead used to set the origin of the analysis.

3. I(1,N-1) are all indices that occur while OPFOR and OWNFOR interact for a specific L7 Mission (Nealon, 2012a). An L5 index will increment when any of the states or parameters in any of the elements within the MMF paradigm experience a change. An L5 index can also increment if a specific amount of time has passed.

4. I(N) is defined as the final L5 index that occurs as the last of the interactions between OPFOR and OWNFOR (Nealon, 2012a).

5. I(N+1) is when the L7 Mission is evaluated for effectiveness with emphasis on the success or failure of key objectives.

The OEL is not limited to being a serial structure and can include branching decisions and outcomes where necessary. An example of one of these branching decisions is when an enemy combatant identifies a friendly system she/he can then make a decision to observe its actions or engage the vehicle with some kind of weapon. If the combatant decides to engage, the OEL will provide an understanding if the system is hit and what could happen during the hit. If the vehicle is still capable of action, then follow-on actions can occur. The decision tree for this example can be found in figure 7.[*]

[*] This entire paragraph is an adaption of comments included in Nealon (2012b).

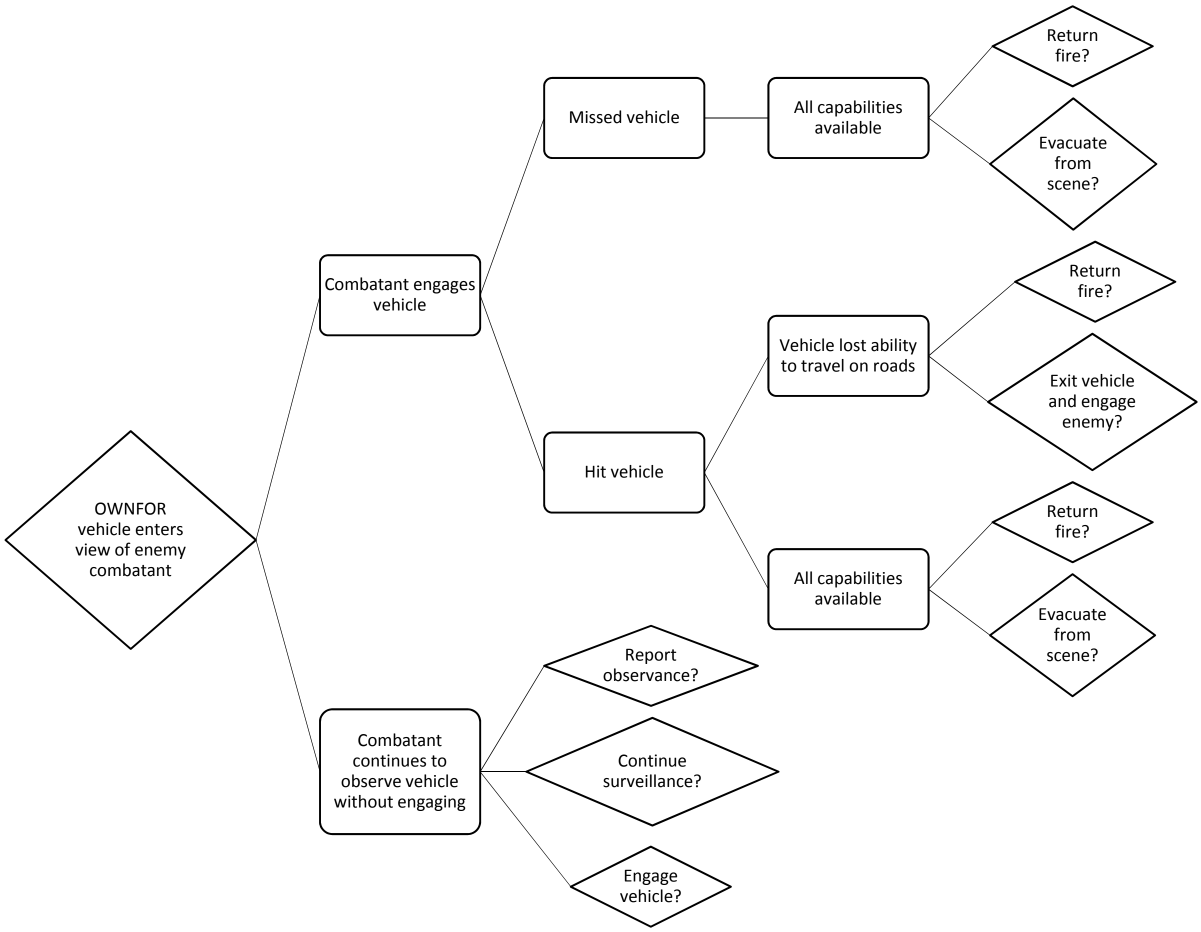

Figure 7. A sample decision tree.

5. Conclusions

One of the key challenges to using the MMF paradigm has been defining the $O_{3,4}$, that is, transitioning from metrics about the L3 system capabilities to the L4 combat utility (Deitz et al., 2009; Walbert et al., 1993; Starks, 1991; Rigotti et al., 1988). The prime reasons are simple: traditional system analysis, especially in vulnerability/lethality (V/L) analysis, had an output of no greater than L3 or mapped directly between L2 and L4, which left the users of the system to define the $O_{3,4}$ and L4 relationships (Deitz et al., 2009; Roach 1996). Because of this separation, metrics could be produced by the system analysts that were not easily consumable by the mission analysts (Deitz and Starks, 1998). With the correlated paradigms, the system-level metrics (the Means) are immediately available for use in the mission analysis (the Missions), as well as all levels being in explicit and quantitative forms. This allows for the construction of the $O_{3,4}$ and for metrics that could be easily understood by the mission analysts.

Because the SCAP FS can be applied to any form of interaction that causes a change in the L2 component state, this allows this combined methodology to be supported by multiple domains of analysis in a parallel manner. Assume a requirements developer and/or mission analyst have decomposed a family of L7 missions into a collection of structured and indexed L4 mission tasks. These individuals use this decomposition to evaluate the performance of a system against a variety of interactions over time, so they employ MMF. Because of their existing work, they can directly populate their mission decomposition into the Missions portion of the framework. They also commission the analysis community to construct the system-level architecture through the SCAP FS. As each analysis domain could provide the appropriate fidelity to their portion of the FS, a single and comprehensive system architecture (the FS) can then be entered into L2, $O_{2,3}$, and L3. This comprehensive FS could include at least the system architecture from the system developer, the fault trees from the reliability analysts, the activation/fault trees from the V/L analysts, the functional relationships for the communications equipment, and the definitions and parameters of the performance of the sensors and equipment from the electronic warfare community.

The analysis community and mission analysts can work together to construct the linkage between the L3 capabilities and the L4 mission tasks, which is the traditionally problematic $O_{3,4}$. The next step is to identify all possible or desirable interactions that the systems within the mission can encounter (the L1 interactions and the $O_{4,1}$) and define a paradigm for how the interactions will be assessed for the $O_{1,2}$. This assessment could be a real-world test, engineering assessments/calculations, physics-based models, or any other form of relevant assessment method. This last step completes the definition of all elements of MMF with a quantitative map.

Based on these correlations, a complex mission analysis within MMF utilizing a SCAP FS can produce a wealth of understanding about how the systems interact, how they will influence each other, and how they can change the performances of each other over time. It should also be possible to develop an understanding of how the individual mission tasks can change based on changing conditions on the systems and their performances. Additionally, the critical system capabilities within the FS can be identified by understanding how the system will be employed. As these correlations exist in a comprehensive, explicit and quantitative architecture across all elements of MMF, a single analytic model now exists that allows for the analysis and assessment of both the Missions and Means.

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List of Symbols, Abbreviations, and Acronyms

AJEM	Advanced Joint Effectiveness Model
AMSAA	United States Army Materiel System Analysis Activity
ARL	U.S. Army Research Laboratory
COIN	Counter Insurgency
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DSVM	Degraded States Vulnerability Methodology
FM	field manual
FS	Functional Skeleton
HMMWV	High Mobility Multipurpose Wheeled Vehicle
I(n)	Index within the OEL at interval n
IDA	Institute for Defense Analysis
JLTV	Joint Light Tactical Vehicle
L1	Missions and Means Level 1, Interactions or Effects
L2	Missions and Means Level 2, Components or Forces
L3	Missions and Means Level 3, Functions or Capabilities
L4	Missions and Means Level 4, Tasks or Operations
L5	Missions and Means Level 5, Index and Location/Time
L6	Missions and Means Level 6, Context or Environment
L7	Missions and Means Level 7, Purpose or Mission
LDT	Light-Duty Truck
LOSAT	Line-of-Sight Antitank
MBT&E	Mission Based Test and Evaluation
MDMP	Military Decision-Making Process

MMF	Missions and Means Framework
MoP	Measures of Performance
NDIA	National Defense Industrial Association
$O_{1,2}$	Operator between MMF L1 and L2
$O_{2,3}$	Operator between MMF L2 and L3
$O_{3,4}$	Operator between MMF L3 and L4
$O_{4,1}$	Operator between MMF L4 and L1
OEL	Ordered Event List
OPFOR	Opposing Force
OWNFOR	Own Force
PK	Probability of Kill
SCAP	System Capabilities Analytic Process
SLAD	Survivability / Lethality Analysis Directorate
TRADOC	United States Army Training and Doctrine Command
USA	United States Army
V/L	Vulnerability / Lethality

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